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Integrating Sunflower Oil Seed Crops into Florida Horticultural Production Systems

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Sunflower (*Helianthus annuus* L.) hybrids, grown as rotation crops in commercial tomato production fields, were investigated for their potential as a biodiesel feedstock. Large, replicated 0.27-ha (0.68 acre) blocks were cultivated to approximate commercial production conditions. Yields of a dwarf hybrid ranged from 1921 to 2008 kg·ha⁻¹ (1715–1791 lb/acre) and were higher than the traditional taller hybrids. Seed oil content ranged from 45.0% to 46.9%. Using a combination of mechanical and chemical expelling, oil recovery from dwarf hybrid seeds ranged from 35.7% to 39.7% and generated oil yields of 746 to 869 L·ha⁻¹ (80–92 gal/acre). Between 1106 to 1142 kg·ha⁻¹ (987–1019 lb/acre) of high nutritional quality sunflower meal was obtained from the oil expelling process. Several key pests were observed that limit applications for sunflower as a beneficial rotation crop for Florida vegetable producers including root-knot nematodes (*Meloidogyne* spp.) and sclerotinia head rot (*Sclerotinia sclerotiorum* Lib. De Bary). Biodiesel produced from crude, decanted sunflower oil was high in quality and passed all American Society for Testing and Materials standards except the Oxidation Stability Index, demonstrating that sunflower rotation crops grown as feedstock for biodiesel production can provide additional revenue to Florida farmers while enhancing sources of traditional food production.

Cover crops or rotational crops are temporary or seasonal vegetative covers grown between primary cash crops. Horticulturally, they can benefit future crops by increasing soil organic matter, improving soil tilth, reducing soil loss from wind and water erosion and mitigating the buildup of soilborne pests. Environmentally, they can protect surface and ground water quality by recycling nutrients remaining from previous crops, alleviating the impact of anthropogenic carbon dioxide emissions into the earth's atmosphere and reducing the application of agricultural pesticides. Despite their many benefits, growers are reluctant to plant cover crops or rotate crops because of the cost and time required to plant and manage them. Generation of direct revenue from their cultivation and indirect revenue through the creation of value-added products would provide additional incentives for Florida growers to integrate rotation cropping into their farm management plans.

Rotation crops that provide feedstock oil for biodiesel production offer the potential for creating additional revenue sources for farmers at the same time that large regional truck and bus fleets are seeking more sustainable local biodiesel sources. Biodiesel is a non-petroleum-based diesel fuel produced from the transesterification of vegetable oil or animal fat. Unlike straight vegetable oil, biodiesel has combustion properties very similar to petroleum diesel and can be freely substituted for petroleum diesel in many uses (U.S. Dept. of Energy, 2004). In Florida, an enormous market for locally generated biodiesel exists. Since 2004, annual consumption of petroleum diesel in Florida has remained above 1.6 billion gallons per year (McDonald and Albanese, 2008) while nationally, estimates of U.S. biodiesel production are closer to 700 million gal per year (Anonymous, 2008). Locally produced biodiesel feedstocks are less prone to oxidative destabilization (rancidity) caused by lengthy storage and transportation conditions, thus providing a higher quality biodiesel product. Further, large regional fleets are seeking to support the local rural communities and source more sustainable biodiesel feedstock to reduce energy lost in transporting fuel while at the same time lowering their overall carbon footprints.

Known mainly as a source of edible oil and seeds, sunflower is also an excellent feedstock for biodiesel production. In Florida, an active oilseed research program involving sunflower was initiated following the 1973 OPEC oil embargo and has continued into the early 1980s (Gallaher, 1982; Green et al., 1979; Kucharek, 1998). Field research trials were conducted in north Florida and the Florida panhandle during the summer months using traditional high linoleic acid sunflower varieties. A study of planting date effects on yield and oil composition included a November planting in southeastern Florida (Robertson and Green, 1981). Regionally, the yield potential of mid-oleic hybrids has been examined over multiple locations in Mississippi (Zheljazkov et al., 2008). Previous studies demonstrating the potential of sunflower in Florida focused on its value as an agronomic cash crop. Successful development of biodiesel seed oil feedstock from beneficial rotation crops cultivated by Florida farmers will necessitate investigation of a broader range of criteria including their compatibility with existing crop production systems, amenability to locally based processing facilities and potential to further supplement revenue through the generation of additional value-added products. The objective of this study was to examine the potential of oil-seed sunflower as a multiple-goal-oriented rotation crop for Florida horticultural systems.

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Materials and Methods

Cultivation. Two field plantings (Fall 2007 and Spring 2008) were conducted on a commercial tomato production farm in St. Lucie County, FL, that had been cropped annually to tomato and pepper since 2000. The soil type was a Pineda fine sand (loamy, siliceous, hyperthermic, Arenic, Glossaqualfs) (Watts and Stankey, 1980). The Fall 2007 planting included three high oil-seed sunflower hybrid cultivars ('S672', '545A', and '660CL', Triumph Seed Co., Ralls, TX) planted into 0.27-ha (0.68 acre) blocks of equal size. Each planting was replicated twice. Hybrid 'S672' is a dwarf, mid-oleic variety, hybrid '660CL' is a standard height, Clearfield® mid-oleic variety and hybrid '545A' is a standard height traditional linoleic hybrid. A 10–1–6 formulation of N–P–K consisting of 50% nitrate nitrogen and 50% ammoniacal nitrogen was broadcast applied and incorporated to a depth of 15 cm prior to planting. Corresponding fertility rates were 120–10–66 kg·ha^{-1} (107–9–59 lb/acre) of N–P–K. Soil tests prior to planting indicated the presence of 190 kg·ha^{-1} (169.1 lb/acre) of P remaining from the previous tomato crops. Seeds were planted on 10 Oct. into 10 cm (25 inches) by 20 cm (51 inches) planting beds at a density of 55,000 seeds/ha (22,000 seeds/acre) with a precision vacuum planter maintained at 25 cm (10 inches) of H_2O. Row spacing was 76 cm (30 inches) and plant spacing (drill) was 23 cm (9 inches). Herbicide (*S*-metolachlor, Syngenta Crop Protection, Inc.) was applied on 21 Oct at 1.17 L·ha^{-1} (16 oz/acre) in 374 L·ha^{-1} (40 gal/acre) of water using a 12-m boom sprayer equipped with flat fan nozzles. Subsurface (seep) irrigation was provided. Liquid sidedress applications of fertilizer were made on 8 Nov. at 16–0–9 kg·ha^{-1} (14–0–8 lb/acre) of N–P–K and 20 Nov. at 54–0–30 kg·ha^{-1} (48–0–27 lb/acre) of N–P–K. Total fertility was 190–10–104 kg·ha^{-1} (171–9–94 lb/acre) of N–P–K. No fungicides were applied. Insecticides (spinosad and *Bacillus thuringensis* Berliner) were applied on 9 and 29 Nov. Seed from 545A, S672, 660Cl were harvested on 5, 11 and 11 Feb 2008, respectively, using a 4.8 m (16 ft) small grain platform attached to a combine. Seed moisture at harvest varied from 16.0% to 21%. Harvested seed was dried overnight (12 h) using forced air, cleaned, bagged and weighed. Seed oil content was measured using nuclear magnetic resonance. The incidence of plant pests was determined by examining 2000 plants per block (13% of the plant population). Prior to harvest, soil samples for nematode analysis were collected by removing and combining soil cores 2.5 cm wide and 15 cm deep from the root zone of each of six plants per block. Nematodes were extracted from 100-cm^3 soil sub-samples with a modified sieving and centrifugation procedure (Jenkins, 1964), identified and counted (Taylor and Sasser, 1978).

The Spring 2008 planting was seeded on the same commercial farm on 13 Mar. 2008. Three separate 0.27-ha (0.68 acre) blocks were seeded. Only the dwarf hybrid 'S672' was selected due to observed lodging problems associated with the taller hybrids in the Fall 2007 planting. Fertilizer with a corresponding N–P–K rate of 134–0–94 kg·ha^{-1} (120–9–84 lb/acre) was incorporated into the soil. Prior to planting, a 10 cm (25 inch) tall by 20 cm (51 inch) wide planting bed was prepared using a no-till bedder. Sunflower was planted at a density of 55,000 seeds/ha (22,000 seeds/acre) using a precision vacuum planter with sunflower planting discs and a vacuum held at 25 cm (10 inches) of H_2O. Row spacing was 76 cm (30 inches) and plant spacing (drill) was 23 cm (9 inches). No herbicide was applied. Subsurface (seep) irrigation was maintained at 30–60 cm (12–24 inches) below the soil surface. A liquid sidedress application of fertilizer was made on 7 Apr. using 12–14–0 kg·ha^{-1} (11–12–0 lb/acre) of N–P–K. Total fertility was 134–14–94 kg·ha^{-1} (131–12–84 lb/acre) of N–P–K. No fungicides or insecticides were applied. Seed were harvested on 2 July 2008 using a 4.8-m (16 ft) small grain platform attached to a combine. Seed moisture at harvest varied from 16.0% to 25%. Harvested seed were dried overnight (12 hr) using forced air, cleaned, bagged and weighed. Seed oil content was measured using nuclear magnetic resonance. The incidence of plant pests was determined by examining 2000 plants per block (13% of the plant population). Prior to harvest, soil samples for nematode analysis were collected by removing and combining soil cores 2.5 cm wide and 15 cm deep from the root zone of each of six plants per block. Nematodes were extracted from 100-cm^3 soil sub-samples with a modified sieving and centrifugation procedure (Jenkins, 1964), identified and counted (Taylor and Sasser, 1978).

Feedstock quality. Oil was mechanically extracted from the seed using an electric powered oil expeller (Model 6, Bar N.A. Inc, Champaign, IL) and collected into 19-L plastic barrels. The oil was allowed to settle in the barrels for several days and then decanted into clean barrels. A secondary chemical extraction was performed on the remaining sediment (70% to 74% oil) to separate the remaining oil using methylene chloride (200 g per liter of sediment). After mixing, the oil was removed using a Buchner funnel and vacuum filtration. The methylene chloride was heat evaporated from the extracted oil using a rotovap. Fatty acid methyl ester preparation was performed using procedures outlined by Litchfield (1972) and profiles were ascertained using gas chromatography/mass spectrometry. Representative oil samples from both S672 crops were sent to a biodiesel production plant (Blue Sky Biofuels, LLC, Oakland, CA) to produce several test batches of biodiesel from the crude sunflower oil (decanted but not degummed). The two batches (from the Oct. 2007 and Mar. 2008 plantings) differed in that the second batch was generated by reacting the sunflower oil under a N_2 atmosphere to reduce oxidation. Laboratory analysis of the biodiesel was conducted to determine the percentage of free glycerin, total glycerin, monoglycerides, diglycerides and triglycerides using the American Society for Testing and Materials (ASTM) method D6584, total acid number using ASTM method D664 and the rancimat oxidation stability index using method 14112. The sunflower meal (byproduct from the mechanical oil extraction) was collected in plastic bins and air dried. A feed analysis was performed on samples (Waters Agricultural Laboratories, Inc., Camilla, GA) to determine the relative moisture, digestible protein, crude fat, crude fiber, total digestible nutrients, ash, nitrate, Ca, and P.

Economic and social sustainability. Variable costs obtained from the two field experiments were used to a derive crop budget for sunflower cultivated as a rotational crop in between vegetable cash crops. Fixed farm costs were attributed to the primary vegetable crop and thus not included in the crop budget. Sunflower oil yields were used to develop estimates of breakeven prices based upon actual and projected yields. Production costs and breakeven prices were projected over a range of planting sizes to provide an indication of cost/profit benefits through economy of scale.

Results and Discussion

Cultivation. In the Fall 2007 planting, yields of the dwarf hybrid 'S672' were ≈300 kg·ha^{-1} higher than the traditional taller hybrids (Table 1). In addition, lodging of the taller hybrids due to wind driven rain was observed. Yield of 'S672' was in

Table 1. Yields of sunflower seed, oil, and meal from field plantings as a rotation crop.

Planting date	Cultivar	Harvested seed (kg·ha^{-1})	Seed oil[z] (%)	Oil recovery[y] (%)	Oil yield (kg·ha^{-1})	Meal (kg·ha^{-1})
10 Oct. 2007	545A	1608.3 kg·ha^{-1} (1434.6 lb/acre)	45.4	34.0	595.8 L·ha^{-1} (63.7 gal/acre)	993.9 kg·ha^{-1} (886.5 lb/acre)
10 Oct. 2007	660Cl	1616.0 kg·ha^{-1} (1441.5 lb/acre)	45.0	36.5	642.9 L·ha^{-1} (68.7 gal/acre)	947.0 kg·ha^{-1} (844.7 lb/acre)
10 Oct. 2007	S672	2007.9 kg·ha^{-1} (1791.0 lb/acre)	46.9	39.7	869.0 L·ha^{-1} (92.3 gal/acre)	1142.5 kg·ha^{-1} (1019.1 lb/acre)
3 Mar. 2008	S672	1921.2 kg·ha^{-1} (1715.4 lb/acre)	45.1	35.7	746 L·ha^{-1} (79.8 gal/acre)	1105.9 kg·ha^{-1} (987.4 lb/acre)

[z]Seed oil content determined by nuclear magnetic resonance.
[y]Oil recovered from seed via mechanical expeller.

the range of yields reported for traditional sunflower varieties grown in Gainesville, FL (Gallaher, 1983; Robertson and Green, 1981) and several locations in Mississippi (Zheljazkov et al., 2008). 'S672' provided higher seed oil content and oil recovery from seed than the taller hybrids (Table 1). Yields of S672 were consistent between the Fall 2007 and the Spring 2008 planting (Table 1). A lower oil yield was observed in Spring 2008 and was attributed to differences in oil recovery (39% vs. 35.7%) not seed oil content (46.9% vs. 45.1%). A substantial quantity of sunflower meal was recovered during the primary mechanical expelling of oil (Table 1). The meal was shown to be a high quality nutritional supplement for livestock based upon high contents of digestible protein, crude fat and total digestible nutrients (Table 2). Additionally, the sunflower meal was low in moisture and ash improving the efficiency of its transportation and distribution. Nitrate concentrations in the meal were 0.2% or less, indicating it could safely be fed to livestock.

Sunflower head rot, caused by *Sclerotinia sclerotiorum*, was observed in the fall and spring plantings. Disease incidence ranged from 0.5% to 5.8% (Table 3). *Sclerotinia sclerotiorum* also causes a wilt and stalk rot of sunflower and is considered one the most prevalent diseases of sunflower on a worldwide basis. While host resistance has been identified in sunflower, it has not been incorporated into commercial sunflower hybrids. Repeated cultivation of sunflower in the same field contributes to the increased disease incidence and should be avoided when sunflower is used a rotation crop in Florida horticultural production systems.

Bidens mottle virus (BiMoV) was observed in both plantings, and reached a disease incidence of 11.7% in the Spring 2008 planting. In Florida, BiMoV is widespread in *Bidens pilosa*, the nearly ubiquitous weed from which this virus was originally described (Christie et al., 1968). BiMoV has also been found to infect multiple vegetable, ornamental and agronomic crops in Florida including lettuce, escarole, endive, gerbera daisy, lark daisy, zinnia, and sunflower (Baker et al., 2007; Kucharek et al., 2003; Logan et al., 1984; Purcifull et al., 1972; C.A. Baker, personal communication). Sunflower infected with BiMoV has also been reported from Taiwan (Liao et al., 2001) and the Taiwan isolate was later shown to be genetically similar to BiMoV isolates from southeastern Florida (Baker et al., 2007; Youssef et al., 2007). The virus is spread primarily by aphids but is also sap transmissible. As sunflower acreage increases in the future, BiMoV could become a limitation to production and thus warrants further investigation into its epidemiology and management

Root galling was observed on all sunflower hybrids in both

Table 2. Nutritional qualities of sunflower meal obtained after crushing (percent wet weight).

Planting date	Cultivar	Moisture (%)	Digestible protein (%)	Crude fat (%)	Total digestible nutrients (%)	Ash (%)	NO_{-3} (%)	Ca (%)	P (%)
10 Oct. 2007	545A	9.0	26.0	17.8	78.2	6.5	0.2	0.3	1.0
10 Oct. 2007	660Cl	9.1	25.0	16.3	75.9	6.5	0.2	0.3	0.9
10 Oct. 2007	S672	8.0	26.1	14.8	75.2	6.7	0.2	0.3	1.1
3 Mar. 2008	S672	9.0	23.8	16.7	75.3	6.6	0.1	0.5	1.0

Table 3. Disease incidence and the density of root-knot nematodes (*Meloidogyne* spp.).

Planting date	Cultivar	Head rot (*Sclerotinia sclerotiorum*)[z] (%)	*Bidens mottle virus*[y] (%)	*Meloidogyne* spp. (no. per 100 cc soil)
10 Oct. 2007	545A	5.4	2.3	8.0
10 Oct. 2007	660Cl	5.8	4.6	544.0
10 Oct. 2007	S672	2.5	2.3	24.0
3 Mar. 2008	S672	0.5	11.7	336.0

[z]Based upon seasonal surveys of 15% of the plant population.
[y]Based upon seasonal surveys of entire plantings.

plantings and *Meloidogyne* spp. were identified in soil samples collected from the base of sunflower plants at harvest (Table 3). *Meloidogyne* spp. are a major pest of many Florida-grown vegetables, including cucurbits, eggplant, pepper, and tomato, and resistance has not been observed in sunflower. Cultivation of sunflower as a rotation crop in vegetable production systems will further exacerbate damage from root-knot nematodes and should be avoided unless a soil disinfestation program for *Meloidogyne* spp. is incorporated into the farm management plan.

While not observed in either planting, it should be noted that bacterial wilt, caused by *Ralstonia solanacearum*, has been reported on sunflower in northern Florida (Kucharek, 1998).

Feedstock quality. The crude sunflower oil pressed from the seed by the mechanical expeller appeared clear and bright after it was allowed to stand and settle for several weeks in a cool environment. The decanted supernatant was used directly for producing test batches of biodiesel by conventional base-catalyzed (sodium hydroxide) transesterification. Commercial production of biodiesel from sunflower would likely require degumming and water washes to remove traces of phospholipid and other impurities.

Biodiesel quality. With the exception of oxidation stability, the biodiesel generated from the crude, decanted sunflower oil passed the most critical test parameters of the ASTM standard D-6751 (Standard specification for biodiesel fuel blend stock for Middle Distillate Fuels) that define biodiesel blending stock (see National Biodiesel Board web site for a full description of ASTM test standard D-6751 specifications, www.biodiesel.org). The data for this initial testing of the 2007 and 2008 batches of sunflower biodiesel were summarized in Table 4. The sunflower batches yielded total glycerin values of 0.035 % and 0.087% for the 2007 and 2008 batches of biodiesel, respectively. This is well below the specification limit of 0.24% for ASTM standard test D-6751. Furthermore, the total glycerin values for both crops were lower than 88% of commercial B100 samples tested in a national survey of B100 biodiesel (McCormick et al., 2006). Free glycerin (percent mass) in the sunflower biodiesel was below the specification limit of 0.02% and lower than 64% of the commercial B100 biodiesel samples collected in the same national survey (McCormick et al., 2006). Hence, the sunflower biodiesel test batches yielded much higher quality biodiesel than typically found in the commercial market in terms of residual glycerides remaining after the transesterification reaction. For the 2007 batch of sunflower biodiesel, the total acid number was 0.42 mg KOH/g. This is below the specification limit of 0.80 mg KOH/g for ASTM standard test D-6751 but higher than 84% of the commercial B100 samples collected in a national survey. However, the 2008 batch of sunflower biodiesel was kept under a nitrogen blanket after expelling the oil from the seed and had a Total Acid number of 0.11 mg KOH/g, which is lower than 76% of the commercial B100 samples in the 2006 national survey (McCormick et al., 2006).

Oxidation stability of the sunflower biodiesel proved to be a problem with both the 2007 and 2008 biodiesel batches. Sunflower oil is high in polyunsaturated fatty acids (Table 5) and as a result, there are more carbon–carbon bonds in the aliphatic chains to react with oxygen. The initial oxidation of the fatty acid chains, whether in the original triglyceride oil or in the finished biodiesel fuel, results in the formation of hydroperoxides. The oxidation of these double bonds to form hydroperoxides could have been accelerated by exposure to air, heat, moisture, and metal ions. Upon further exposure to oxygen and stressful conditions (heat, moisture, metal ions, time), the hydroperoxides continue to break-down by cross-linking to each other (forming insoluble polymer precipitates) or breaking apart and forming short-chain fatty acids (two carboxylic acids from each half of the former double carbon bond). The increase in fatty acid content was measured by the total acid number and the decrease in oxidation stability was measured by the oxidation stability rancimat method. The oxidation stability rancimat method measured the length of time the product is exposed to a stream of oxygen before it induces a sharp change in conductivity known as the induction period. The induction period for the 2007 batch of sunflower biodiesel was only half an hour whereas the minimum specification for

Table 4. American Society for Testing Materials test results for biodiesel produced from crude, decanted sunflower oil (cv. S672).

Test	Method	Limit	10 Oct. 2007 planting date	3 Mar. 2008 planting date
Free glycerin	ASTM D6584	Max 0.02	0.003%	0.000%
Monoglycerides	ASTM D6584	Not available	0.023%	0.076%
Diglycerides	ASTM D6584	Not available	0.007%	0.008%
Triglycerides	ASTM D6584	Not available	0.003%	0.003%
Total glycerin	ASTM D6584	Max 0.24	0.035%	0.087%
Total acid number	ASTM D664	Max 0.80	0.42 mg KOH g^{-1}	0.11 mg KOH g^{-1}
Oxidation stability index	EN 14112	Min 3.00 h	0.52 h[z]	1.26 h[z]

[z]Exceeds American Society for Testing Materials standards.

Table 5. Fatty acid methyl ester (FAME) profiles for oil extracted from harvested sunflower seed in the 10 Oct. 2007 field experiment.

	Hybrid 545A		Dwarf hybrid S672		Hybrid 660 CL	
FAME[z] (%)	2006	2007	2006	2007	2006	2007
Methyl palmitate ($C_{16:0}$)	4.3	4.5	4.3	4.1	4.5	4.9
Methyl stearate ($C_{18:0}$)	2.0	3.3	2.1	2.4	1.7	2.4
Methyl oleate ($C_{18:1}$)	11.5	12.6	51.0	48.1	40.7	43.1
Methyl linoleate ($C_{18:2}$)	81.0	77.0	40.7	43.5	51.2	46.8

[z]Others detected at low concentrations (<0.1%) were methyl myristate ($C_{14:0}$) , methyl palmitoleate ($C_{16:1}$), methyl arachidate ($C_{20:0}$), methyl behenate ($C_{22:0}$), and methyl lignocerate ($C_{24:0}$).

biodiesel blending stock is 3 h (U.S. Dept. of Energy, 2004). The European Union standard is 6 h and the national average among commercial biodiesel samples was approximately 5 h. The 2008 batch, kept under a nitrogen blanket after expelling the oil, had a higher induction period of 1½ h but still fell short of the 3.0-h minimum requirement to pass as acceptable biodiesel fuel. It is suspected that oxidation of the original sunflower oil during mechanical expelling may have formed hydroperoxides leading to lower oxidation stability in the processed fuel. The expelled oil was collected into used metal 492-L (50 gal) drums, where it was allowed to settle for 5–7 d before decanting. Presence of metal ions in the drums including iron oxide, may have accelerated the oxidation of oil particularly in the presence of moisture. Reducing exposure to oxygen during the transesterification helped improve both the oxidation stability index and the total acid number in the second test batch of sunflower oil.

Commercial production of sunflower biodiesel would require more attention to reducing exposure of the seed and expelled oil to heat, moisture, metal ions and oxygen. For example, better mechanical expelling methods exist to allow for "cold pressing." Oxidation during seed storage can be mitigated by reducing drying temperatures and by purging seed bins with nitrogen if the seed will be stored for long periods of time. Expelled oil can be stored, transported and reacted under a N_2 atmosphere to further reduce oxidation. The final biodiesel product can then be treated with commercial antioxidants (and metal chelating agents, as needed) to further preserve the integrity of the sunflower fuel. It should be noted that the high degree of unsaturation of sunflower biodiesel confers much better cold flow properties for the fuel. The cloud point of sunflower oil biodiesel is near or below freezing (0 °C). The lower cloud point affords the opportunity to blend the product with other biodiesel blending stock of higher cloud point (e.g., biodiesel derived from recycled cooking oil, animal fats, tropical oils such as palm and coconut) so that the resulting blends have better cold flow performance and more tolerance to storage and use in winter.

Economic and social sustainability. Sunflower budget projections and breakeven costs were estimated at several production scales for a yield of 2016 kg·ha^{-1} (1800 lb/acre) with a net return of 869 L·ha^{-1} (93 gal/acre) (Table 6). For a 200-acre production size, breakeven costs were estimated at $0.30 per pound of harvested seed or $5.87 per gallon of crude sunflower oil. These breakeven estimates declined to $0.26 per pound of harvested seed or $5.07 per gallon of crude sunflower at a 2000-acre production scale. Not figured into the budget projection was the cost of expelling the oil (seed crushing), additional revenue generated from the sunflower meal obtained after expelling the oil, and fixed costs associated with agricultural production.

Cultivation of sunflower in Florida as a rotational crop to complement existing horticultural production systems has the potential to provide supplementary revenue streams for rural economies, improve soil fertility, sequester additional carbon from the atmosphere, and provide a local supply of renewable fuel that does not compete with food production. These criteria improve the social sustainability of sunflower production. However, it should be noted that several key pests of sunflower were observed including root-knot nematodes and *Sclerotina* head and stalk rot that may limit its range of cultivation as a beneficial rotational crop in Florida. This caveat should be recognized as sunflower acreage in Florida is expanded and additional oil seed crops are cultivated.

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Table 6. Sunflower budget projection and breakeven costs at several production scales.

Task	80 ha (200 acres)	800 ha (2,000 acres)	8,000 ha (20,000 acres)
Pre-plant disking (twice) and preparation of planting beds[z]	$110/ha ($44/acre)	$110/ha ($44/acre)	$110/ha ($44/acre)
Granular fertilizer (preplant)[y]	$682/ha ($273/acre)	$545/ha ($218/acre)	$410/ha ($164/acre)
Liquid fertilizer (sidedress)[x]	$188/ha ($75/acre)	$150/ha ($60/acre)	$112/ha ($45/acre)
Herbicide[w]	$60/ha ($24/acre)	$50/ha ($20/acre)	$45/ha ($18/acre)
Hybrid seed (22,000/acre)	$65/ha ($26/acre)	$65/ha ($26/acre)	$65/ha ($26/acre)
Planting (4-row planter)	$28/ha ($11/acre)	$28/ha ($11/acre)	$28/ha ($11/acre)
Overhead irrigation (2x) and pump costs for seepage	$158/ha ($63/acre)	$158/ha ($63/acre)	$158/ha ($63/acre)
Harvest (combines)	$75/ha ($30/acre)	$75/ha ($30/acre)	$75/ha ($30/acre)
Total variable costs	$1,366/ha ($546/acre)	$1,180/ha ($472/acre)	$1,002/ha ($401/acre)
Breakeven cost per wt of seed[v]	$0.68/kg ($0.30/lb)	$0.57/kg ($0.26/lb)	$0.48/kg ($0.22/lb)
Breakeven cost per vol of oil	$1.55/L ($5.87/gal)	$1.34/L ($5.07/gal)	$1.14/L ($4.31/gal)

[z]Disk capacity = 20 min/acre, tractor uses 6 gal diesel/h at $2/gal, and labor = $12/h.
[y]Based upon 120–10–66 kg·ha^{-1} (107–9–59 lb/acre) of N–P–K.
[x]Based upon 70–0–39 kg·ha^{-1} (62–0–35 lb/acre) of N–P–K.
[w]Bed upon *S*-metolachlor (Syngenta Crop Protection, Inc.) applied at 1.17 L·ha^{-1} (16 oz/acre) in 374 L·ha^{-1} (40 gal/acre) of water using a 12-m boom sprayer equipped with flat fan nozzles.
[v]Based upon yield of 2016 kg·ha^{-1} (1,800 lb/acre).
[u]Based upon oil yield of 869 L·ha^{-1}(93 gal/acre).

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